

1900-1901

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1900

THE PLANT OF THE ST. CROIX POWER CO. OF WISCONSIN.

BY HENRY FLOY.

INTRODUCTORY.

The considerable number of high-tension long-distance transmission plants already in successful operation, might not render the completion and starting of a 25,000 volt plant of any particular interest, except that in all engineering work and especially in electrical lines, the "newest" usually means something of a change from, and improvement upon anything previously constructed.

There are, however, some features both hydraulic and electrical connected with the plant of the St. Croix Power Company, recently put into operation which I think will prove of more than ordinary interest to the members of this INSTITUTE.

GENERAL DESCRIPTION.

About two years ago the St. Paul Gas Light Company of St. Paul, Minn., owing to increasing business, the depreciation and antiquity of its generating apparatus and the expense of operating four distinct stations, foresaw that it must build a single modern and larger steam generating plant or arrange for securing current by means of long-distance transmission through the development of one or more of the water powers within reasonable distance of St. Paul.

Upon investigation it was found that 27 miles east of St. Paul, on Apple River, in the State of Wisconsin, there was a natural fall of about 30 feet. Above the fall a dam could be built to

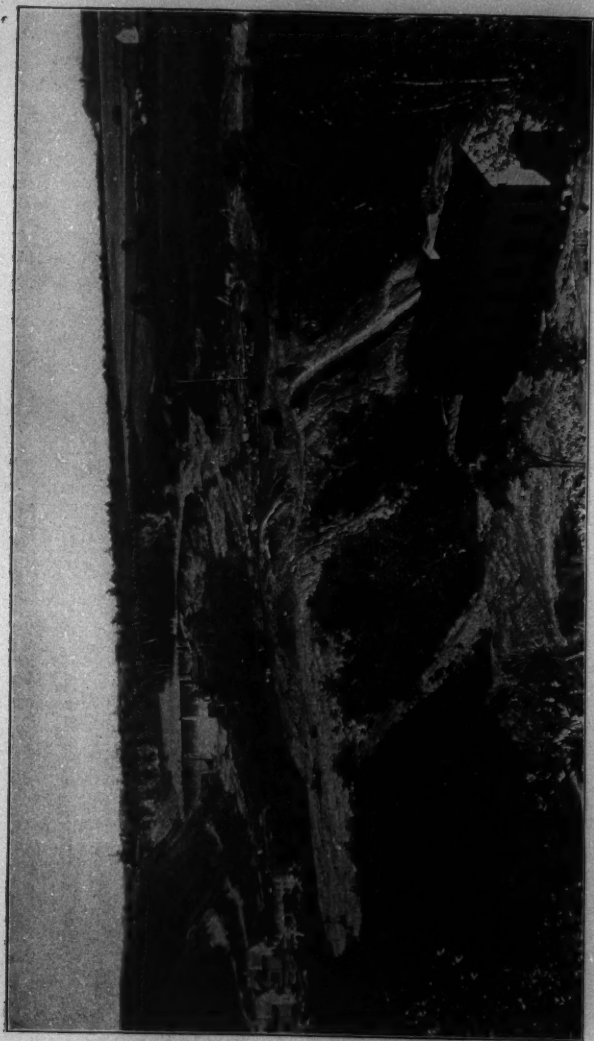


FIG. 1.—General View of Property, St. Croix Power Co.

a height of 47 feet thus affording with a slight drop in the river below the fall a total head of 82 feet. Apple River is fed from innumerable springs and some 25 lakes in north-western Wisconsin and in consequence its discharge is remarkably uniform the year around. With the head afforded, the minimum flow of water in the stream would yield about 2,000 H. P. continuously and during most of the year nearly twice that amount. By the building of a dam, a large reservoir would be formed from which

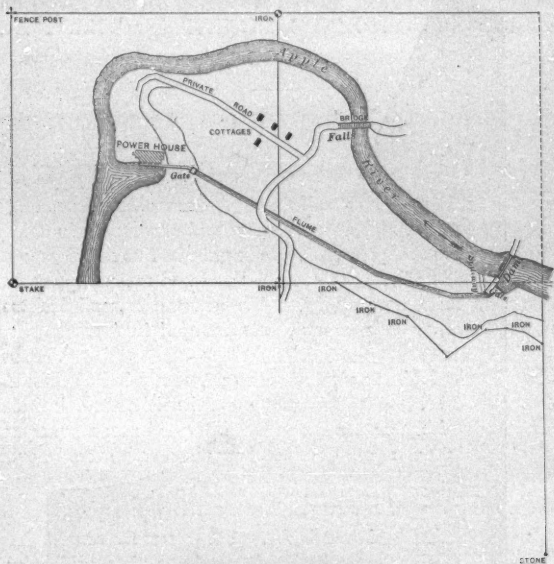


FIG. 2.—Plan of Property.

the impounded water could be drawn in any quantity necessary to carry the peak of any load in St. Paul, provided sufficient capacity was installed in water-wheels, generators and transmission line. It was thus demonstrated to the St. Paul Gas Light Company that the power that could be made available at Apple River Falls by a development of the character just outlined, would permit not only the complete shutting down of its four steam plants and avoid the necessity for building a modern

steam plant but also provide it with nearly twice the saleable output of its old stations.

Accordingly, about a year and a half ago, there was organized under the laws of the State of Wisconsin the St. Croix Power Company. This company is friendly to the St. Paul Gas Light Company and to the latter the former contracted to sell all the current it could generate by the development of a power plant at Apple River Falls.

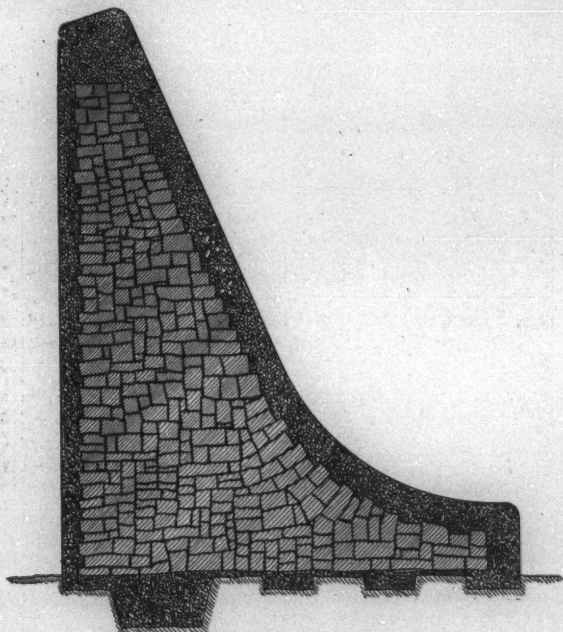


FIG. 3.—Section through Spillway of Dam.

HYDRAULIC DEVELOPMENT.

The accompanying map, Fig. 2, shows the property purchased outright by the power company, and gives a very good idea of the location of the original falls and the present dam, flume and power-house. Above this property only the right, to flow such land as would be inundated by the storage reservoir, was acquired.

Owing to the inaccessible location of the dam, being about five miles from a railroad station, and the country very rough and hilly, the importation of building stone for the dam was out of the question. The only material available at the falls is a brown sandstone, somewhat harder than the St. Peter rock underlying much of St. Paul and Minneapolis, but not hard enough to withstand constant attrition of the water. It was therefore decided to build the dam with a masonry core, resting on concrete foundations and enclosed in concrete facings.



FIG. 4.—The Dam and Flume Looking Down Stream.

The masonry core was not carried higher than within six feet of the crest of the dam, and was built of uncoursed rubble masonry laid in Portland cement mortar, consisting of three parts of sand to one of cement. Both the sandstone and unlimited quantities of clean sharp sand were found on the company's property.

The concrete, not only in the dam but forebay, power-house and machinery foundations was composed of one part by measure of Portland cement, three parts of sharp sand mixed with four parts of broken stone. The broken stone was obtained by crushing granite trap or gneiss boulders, commonly called "nigger heads" into cubes not larger than three and a half inches or

smaller than one inch; the "nigger heads" being collected from neighboring farms.

Fig. 3 shows the cross-section of the dam through the spillway. It will be noted that the dam is carried down below the level of the bed-rock in the center of the stream to a depth of almost five feet in one broad trench, and that there are three other trenches about a foot deep running entirely across the bed of the stream. The banks of the river which rise twenty-five or thirty feet above the top of the dam are composed of solid sandstone. Into these the dam is carried some twenty-five feet on the north bank and eighteen feet on the south bank. The main seepage trench along

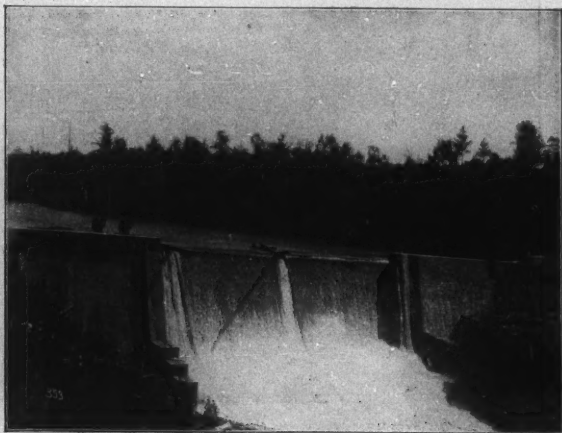


FIG. 5.—Dam and Spillway.

the bottom of the dam being carried up and well into both river banks to absolutely cut off any chance for seepage around the ends of the dam. All seepage trenches were filled and all exposed rock covered with concrete before any masonry was laid. The concrete facings on the up and down stream sides and top were, of course, tamped in between the masonry and wooden forms.

The dam is of the arched type, being built as the arc of a circle having a radius of 450 feet. Near the north bank, close to the bed of the river, two steel pipes, each five feet in diameter are

built into the concrete work and fitted with gates and crabs to permit control of the water while constructing the dam, or in time of repair, and the regulation of flow over the spillway in case of unusually high water.

At the south end of the dam are the trash racks and near them a sluice for conveniently disposing of the debris and ice.

The length of the spillway is 108 feet, and the total length of the dam 350 feet. There are 3138 cubic yards of concrete and 5025 cubic yards of rubble masonry in the dam.

Incidentally it may be mentioned that when carrying the north end of the dam into the sand rock, a spring was encountered. This was taken care of by laying a pipe for it to discharge through, then building the dam right up and around it.

There has been some controversy as to whether concrete dams are satisfactory, especially in northern latitudes, and the dam here described, although only partially of concrete, will add, I think, another argument in their favor.

It is a pleasure to state that although this dam has experienced extremes of temperature and stresses, it does not show any signs of cracks or leakage, and a number of engineers, experts on this class of work, who have seen the dam since its completion, unanimously agreed that the concrete work is of the highest grade, and that the dam as a whole is a most perfect monolith.

While it is too early to determine the ultimate success of this construction, satisfactory results thus far accomplished are due primarily, I believe, to the following:

First.—All materials in the concrete were of the very best quality. Alsen and Atlas cements were used exclusively, and severe tests made continuously to ensure no deterioration in the grade of cement.

Second.—No concrete was laid and allowed to freeze before setting. The work was started early in September, a year ago, and the autumn was most favorable for outdoor work, which was carried on without interruption until the middle of December, then closed down by cold weather. At that time the north end of the dam had been completed and the south half brought up to within about 18 feet of the top. It stood in this condition throughout the winter and until April 5th, when authority was given the contractor to proceed with the work.

Third.—Although the dam was wholly complete about May 1st, it was allowed to stand almost two months before the waste gates

The flume is constructed entirely of wood, caulked with oakum and braced by both vertical and horizontal tie rods. The bottom stringers are of Oregon fir, which is a superior grade of pine, particularly free from knots and imperfections, found in Washington, Idaho and Oregon and becoming very largely used in the northwest. The remainder of the timber in the flume is Norway pine, except the tongues which are white pine. Fig. No. 6 shows the cross-section of the flume as built, which is of the same dimensions throughout its length. The flume rests on excavated foundations, is level throughout its length, filled on both sides and covered to a depth of two feet with earth.

With a velocity not exceeding three feet per second, it was designed to convey 670 cu. ft. of water per second being sufficient to generate 5000 H. P., under an 82-feet head with wheels having an efficiency of 80%.

The forebay at the lower end of the flume is located about 100 feet back from the brow of the hill. It consists of a rectangular steel box, 24 feet wide, 24 feet long and 17 feet deep and is designed to connect the flume with, and serve as an anchorage for the penstock, and also to afford a place in which to locate gates and racks. The steel box is built of $\frac{3}{8}$ " steel, rigidly supported by I beams and braces. It rests on a concrete foundation and is supported on all sides by heavy masonry walls, 12 feet thick at the bottom. One of the end walls is pierced by the flume, and the other by the flared mouth of the penstock which is securely riveted to the box and flanged into the supporting wall. Just in front of the forebay and at right angles to and extending ten feet below the bottom of the flume, is a concrete cut-off seepage wall, 42 feet long and three feet thick, designed to prevent the possibility of any water leaking through and following along the sides of the flume and attacking the forebay foundations.

At the head of the flume and close to the dam there is a lateral overflow or waste weir, connected with the side of the flume, and designed to prevent the water in same rising above a predetermined point and putting the top of the flume under pressure. This waste weir is about 27 feet in width and slopes from the side of the flume to the bank of the river. It is designed to automatically prevent any increase in the level of the water in the flume, regardless of how much the water in the reservoir may rise—within reasonable limits—above the spillway. The level of

the upper end of the weir where it joins the flume is the same as that of the spillway, but by means of small gates the level of the overflow may be raised to the top of the flume if desired.

In the dam at the head of the flume are three head gates and the iron trash rack previously referred to, while at the lower end of the flume in the forebay are three tail gates with finer trash rack.

The penstock is 12 feet in diameter. It takes its beginning in the forebay and extends in a horizontal direction 88 feet to the brow of the hill, down which it continues 107 feet at an angle of

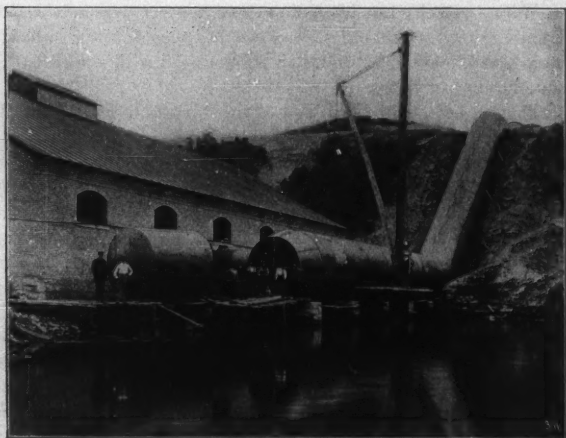


FIG. 7.—12 feet Steel Penstock.

about 45° . Then it turns again and continues in a horizontal direction 118 feet further. The penstock is of open hearth steel plate, $\frac{3}{8}$ " thick above the elevation 140.61 and $\frac{1}{16}$ " below that elevation. The sheets of which the penstock is composed are held together by rivets, spaced $2\frac{1}{2}$ " on centers, all rivet holes being punched $\frac{1}{16}$ " small and reamed out to full size; all joints being caulked and the whole painted with an iron preservative paint. The penstock is supported throughout its length on suitable masonry piers. On the hill-side, the earth has also been tamped under the pipe to give it additional support. The lower

end of the penstock is provided with four branch pipes supplying four main sets of waterwheels, and a smaller fifth branch pipe ending in a "Y" supplies two separate exciter wheels. At the lower end of the penstock is provided a gravity automatic relief valve having a discharge 12" in diameter. The last section of the penstock is provided with a blank opening for an additional and fifth unit in case it ever becomes desirable to install the same.

GENERATING STATION.

The generating station is a fire-proof structure of brick and iron, about 140' x 50', divided longitudinally by a partition wall, thus separating the wheel-room from the dynamo-room. (See Fig. 8.)

In the wheel-room are four main sets of waterwheels, space being reserved for the fifth unit which may be added later. Each set consists of two 36" special "Victor" wheels, mounted horizontally in a nine feet cylindrical steel wheel-chest from which they discharge through a six feet draft tube, eight feet long. Each pair of wheels is, of course, on a single shaft which extends through the end of the wheel-chest built into the partition wall, and is direct connected to a 750 k. w. generator. Each wheel-chest is supplied from the penstock by its own feeder pipe in which is located a 56" gate-valve operated from a shaft driven by a $7\frac{1}{2}$ h. p. electric motor. Each wheel-chest is surmounted by an automatic spring relief valve having an opening 12" in diameter. There are two exciter wheels, each direct connected to a 30 k. w. direct current generator. The exciter wheels have their own branch feeder pipes, wheel-chests and separate gate-valves.

The waterwheel governors are of an improved type of the Giesler pattern. They are guaranteed to maintain the speed within 3% of normal for any instantaneous change in load not exceeding 25% of the load at the moment of variation. The governors are electrically controlled, being operated by the 125-volt exciter current.

All the alternators are 750-k.w., three-phase, 800-volt, 60-cycle revolving armature, separately excited machines, running at 300 r. p. m. They will carry full load continuously without heating more than 40° C. above the temperature of the surrounding air, and have an inherent regulation slightly under 5% on non-inductive load.

transformer panels, and a local service panel. The exciter panel is supplied with the usual instruments, but the alternator panels are each equipped with one main oil switch, in series with two triple-pole quick-break jaw switches, for throwing the machine onto either two sets of 'bus-bars. At the top of the panel is an ammeter, an indicating wattmeter, and a field ammeter with the usual synchronizing lamp, field-switch and voltmeter plug. The transformer panels will each be provided with an induction recording wattmeter, a single three-phase oil switch of special design, having a capacity of 1500 k. w. at 800 volts, and a potential indicator which enables operators at the generating station switchboard to determine the voltage at the St. Paul sub-station, regardless of the power factor of the load or the drop in the line.

A brief description of this type of potential indicator may not be amiss. Across the terminals of the main transformer leads is connected a small transformer supplying in its secondary circuit, an E. M. F. in step with, and proportional to that of the generator. In series with the main transformer leads is a small series transformer which supplies in its secondary circuit a current always in step with, and proportional to its primary current. The secondaries of the two transformers are connected in series through an inductive resistance and an ohmic resistance. Both the inductive resistance or reactance and the ohmic resistance are so adjusted that for a given current through them, their respective E. M. F.'s have the same value relative to the E. M. F. of the potential transformer as the reactance and resistance E. M. F.'s of the transmission circuit have to the E. M. F. of the generator. Therefore, the local reactance and resistance E. M. F.'s reduce the E. M. F. supplied by the potential transformer to a potential indicator connected in this local circuit, in the same proportion as the line reactance and resistance E. M. F.'s cut down the generator voltage, and thus the potential indicator at the generating station is made to indicate the voltage at the point of distribution.

The local service switchboard panel is equipped with switches for controlling the electric heaters by which the power-house is warmed, also the incandescent and arc lighting circuits and the motors driving the blowers.

There have been installed six air-blast transformers of 500 k.w. capacity each, which step the voltage up directly from 800 to 25,000 volts. As operated, the transformers are connected in two sets of three each with "Y" connections. The low-tension side

of each set of transformers is joined directly with the transformer panel switches, and the high-tension side with Westinghouse "spider" switches, through the use of which either bank of transformers may be connected to either or both of the transformer circuits.

All the electrical apparatus in the power plant was furnished by the General Electric Company, except the high-tension switches and the alternating current arc lamps, which latter were purchased from the Manhattan General Construction Company. These lamps are of the enclosed type and require 6.6 amperes. They are operated in series directly from the 800-volt 'bus-bars, there being eight lamps and regulator in each circuit.

A 20-ton hand crane traveling the entire length of the dynamo-room, affords a convenient method for handling the heavy machinery.

TWENTY-FIVE THOUSAND VOLT OVERHEAD AND UNDERGROUND TRANSMISSION LINE.

Two three-wire, three-phase transmission circuits, each consisting of $24\frac{1}{2}$ miles of overhead bare copper wires and three miles of underground cables connect the generating plant with the distributing station in St. Paul.

Both overhead circuits are carried on a single line of poles. The wires of each circuit are on one side of the poles and are supported so as to be at the vertices of an equilateral triangle, having 24" sides. The conductors are of No. 2, B. and S. medium hard-drawn copper wire, carried on glass insulators of the "Provo type"—the same as those used on the 40,000-volt transmission in Utah. The insulators are 7" in diameter and have a triple petticoat. They are mounted on special locust pins boiled in paraffine, carried on two 4' x 5" Oregon fir cross-arms. The poles are mainly of Oregon fir and are spaced not more than 110 feet apart. No poles less than 30 feet in length and eight inches in diameter at the top are used. Poles of minimum length are planted $5\frac{1}{2}$ feet in the ground and six inches deeper for every additional five feet in their length. The line was designed to be practically level, irrespective of configurations in the earth's surface. The corners and angles in the line are reduced to as few as possible, consistent with securing a right-of-way at a reasonable price; no angle in a conductor at any insulator is less than 165° .

thus avoiding any dangerous tendency to break the pins. In making a right angle turn special construction is used (see Fig. 9) affording seven points of support for each wire. For slight turns two or three poles as may be required, are set ten feet apart but no more than one insulator per wire is allowed on a single pole.

The transmission line really takes its beginning at the terminals of the step-up transformers in the dynamo-room of the gene-

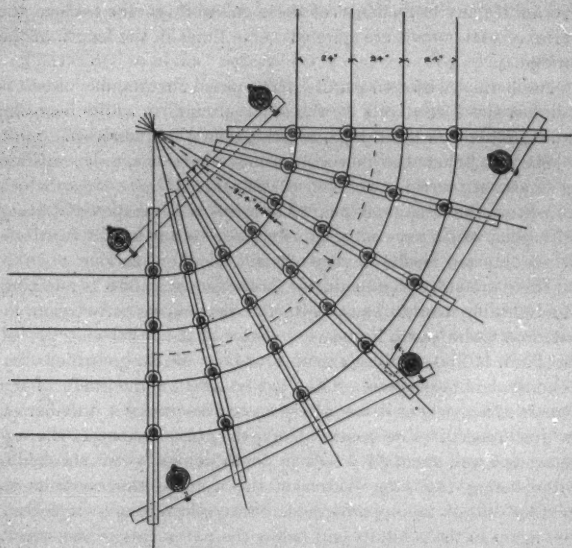


FIG. 9.—Special Corner Construction.

rating station, whence it passes through the Westinghouse high-tension switches into a brick lightning arrester house abutting against the end of the power-house. Here are located choke coils and lightning arresters. From the arrester house the wires pass out through circular openings in the wall which are sheltered by a gabled roof and run thence in a general western direction to a similar arrester house in the city of St. Paul, where they terminate in the heads of the underground cables.

No especial engineering difficulties were met with in the construction of the aerial line, except in crossing the St. Croix river which is about a half mile wide, with precipitous banks 100 or more feet in height. Advantage was taken of a bridge built by the Wisconsin Central Railway, and long oak pieces were fitted between the ties every 50 feet throughout the length of the bridge. These oak pieces project about 20 feet beyond the edge of the bridge and on them the six wires are carried in a horizontal plane. To nullify any bad effects of the iron work in the bridge, the wires of each circuit are spiraled three times in the length of the bridge.

As is usual with two parallel three-phase circuits, one circuit is spiraled twice relatively to the other circuit, in addition to the transpositions on the bridge, to prevent mutual induction.

Six feet below the power transmission circuit, on a separate cross-arm are carried two No. 10 galvanized iron wires, which constitute the telephone line. The wires are transposed at every fifth pole, which very satisfactorily prevents any inductive effects in the line and results in very efficient telephone service.

There are two three-conductor lead-covered cables connecting the lightning arrester house with the distributing sub-station located on Cedar street in the very center of the business section of St. Paul. These cables are in four-hole McRoy vitrified clay conduits laid in concrete. The conduits follow the grade of the streets except where it was necessary to pass under a number of railroad tracks in a deep cut. Here, the conduits end in the top of a brick well about fifty feet in depth, down which the cables drop passing from the bottom of the well in other conduits to another well on the opposite side of the tracks through which they rise again to the conduits laid below the pavements of the street.

In considering the use of cables for 25,000-volt transmission under ground, the writer found that a number of reputable manufacturers not only declined to bid on his specifications, but would not entertain any proposition for furnishing such cables, even under their own specifications. There were only two companies that were anxious to undertake the work and accordingly a contract was entered into with these companies, one to furnish a rubber insulated and the other a paper insulated cable.

The specifications provided that the general design of both cables should be the same, that is, each conductor having an area not less than 66,000 cm., is composed of seven strands of copper

wire, enclosed in insulation, the three laid up in jute and the whole enclosed in a jacket of the same insulating material as that used about each conductor. Outside of the jacket is the lead sheathing $\frac{1}{8}$ " in thickness, making the cable complete about $2\frac{1}{4}$ " in diameter.

The "National" cable is insulated with paper treated with a secret compound. The insulation about each conductor is $\frac{9}{32}$ " in thickness. That of the enveloping jacket, $\frac{4}{32}$ " thick. The covering of this cable is of lead protected on the exterior by a coating of tin.

The insulation of the "Safety" cable is about a 35% compound of the best "old up river" Para rubber $\frac{7}{32}$ " thick around each conductor, wrapped with a drilled tape served with jute, with the jacket $\frac{5}{32}$ " thick. The sheathing of this cable is of lead, mixed with 3% of tin.

The contracts entered into with the above companies for cables included not only their manufacturing the cables and testing them to 40,000 volts in their factories before shipment, but also the installation of the cables complete ready for operation in the conduits in St. Paul. The contracts further include a guarantee for a period of five years protecting the purchaser against any breakdown in the cables, except those due to extraneous and mechanical injuries, and further permitting at any time during that period, the testing of the cables *in situ*, up to a potential of 30,000 volts. The writer's aim in having the contract for each cable awarded to a separate company was to secure the benefits of competition, in promptness of delivery and perfection of manufacture. Furthermore, as underground work of such tension had never been attempted before, there was some question as to whether rubber or paper would prove the more durable insulator under these conditions.

While of course, the ultimate success of 25,000-volt underground transmission can only be determined by the lapse of time, and the action of high voltage in its effect on the insulation, nevertheless the success in operating seems to have demonstrated the wisdom of the experiment and great credit must be given to the manufacturing companies for their co-operation in undertaking what had never before been attempted and what many manufacturers prophesied would result in failure.

The calculated resistance of each conductor between the generating and distributing stations is 23. ohms. The drop in voltage between the same points, for 3,000 k. w. delivered with a 90%

power factor, and 25,000 volts initial potential, figures 7.7% operating both lines in multiple which will be the usual practice.

SUB STATION AND APPARATUS.

The distributing station in St. Paul is an iron and brick building designed to contain the necessary apparatus for reducing the potential and controlling and transforming the energy received over the transmission line, for distribution in the City of St. Paul. The building is 50' x 65', two and a half stories in height. One-half of the building has a basement divided into two rooms, one, in which all the static step-down transformers and high-tension switches are located, is connected by a tunnel with the street conduits; the other serves as a toilet room and place in which to locate the apparatus for heating the station. (See Fig. 10.) The main floor is divided into three rooms, open to the roof. The larger room, 50' x 50', contains six 250 k. w. rotary converters and two marble switchboards, extending along two sides of the room. The second room on this floor serves as a hallway to the main room, and affords a place in which to locate telephone box, etc. The third room is open from the roof to the basement but is entirely cut off and separated from all the rest of the building, except for a single door from the hallway. This room is intended for a storage battery, which it is planned to install later.

Each conductor of two high-tension cables passing through the tunnel into the transformer room, ends in one terminal of a single-pole knife switch, to be operated only when current is off the line and installed to permit convenient testing of cables, etc. The other terminal of each switch is connected to a high-tension 'bus-bar, from which taps are taken off to the high-tension switches controlling the circuits to the different sets of transformers. The ends of the cables are also connected to static discharges, which are merely a number of standard lightning arresters, connected in series.

The high-tension 'bus-bars and their taps to the high-tension switches and from the switches to the transformers, are single conductors insulated with $\frac{1}{4}$ " of best Para compound, and guaranteed to withstand 25,000 volts continuously. The conductors are carried in conduits made of wood pulp indurated with asphaltum, manufactured by the Fibre Conduit Company. The conduits are guaranteed to withstand 20,000 volts without breaking down.

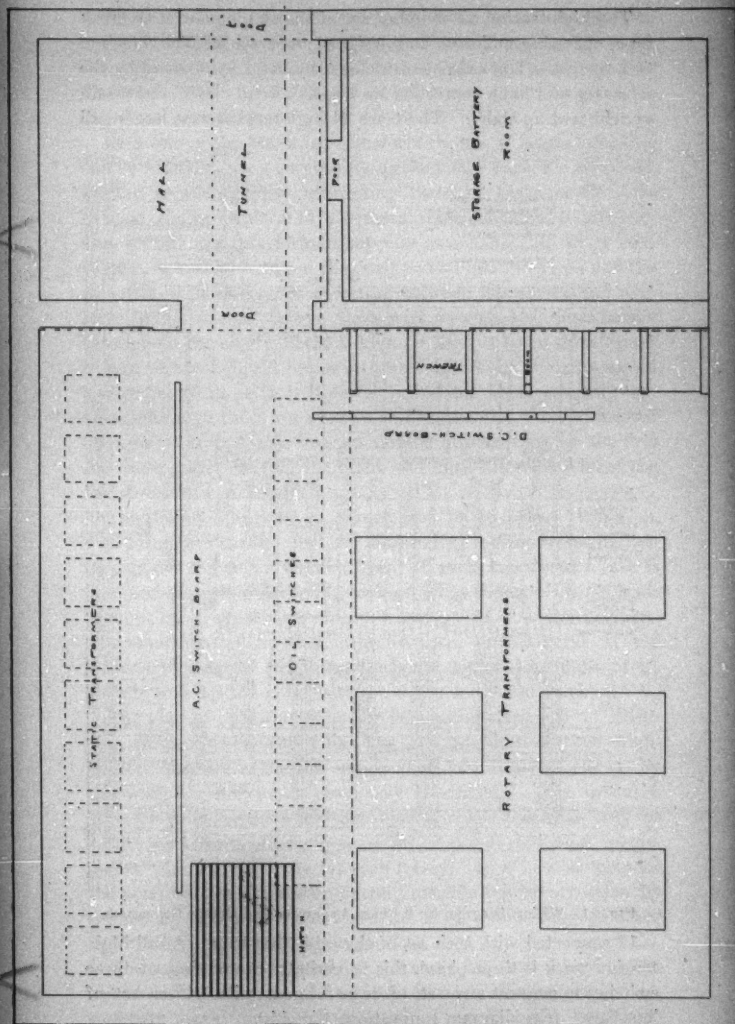


FIG. 10—Transformer Sub-station.

There are four banks of static step-down transformers—two banks consisting of three 22,500 to 78-volt oil-cooled 300 k. w. three-phase to six-phase transformers and two banks of two 22,500 to 2,100–2,700-volt oil-cooled 200 k. w. three-phase to two-phase transformers.

Each one of the 300 k. w. transformers has a single winding on the primary, and two entirely distinct and separate windings on the secondary. By connecting three of these transformers in a set, the three-phase to six-phase transformation is effected. One set of these transformers supplies current to the rotary converters, operating between the positive and neutral wires, and the other set to those rotaries operating between the neutral and negative wires of the Edison three-wire system of distribution throughout the city. There is kept on hand a spare transformer in case of break-down, but as all transformers in the sub-station are connected in delta, it is perfectly feasible to successfully operate, although there are but two transformers of a set connected in circuit. In fact, this was the method of operating for the first few weeks after starting the plant and until the remainder of the transformers were received.

The two identical sets of three-phase to two-phase 200 k. w. transformers provide for the alternating current distribution throughout the city. On the front of each transformer case is mounted a quick-break multipoint switch connected with leads brought out from the secondary windings of the transformers. The movement of the switch throws more or less turns of the secondary in circuit and thus adjusts the potential in steps of 21 volts to any desired point between 2,100 and 2,700 volts.

The plan of operating from the generating station is to maintain irrespective of load or line loss, the potential on the high-tension 'bus-bars in the sub-station at 22,500 volts, as shown by the potential indicators previously described. This potential gives 78 volts for the rotary converters which potential may be varied seven volts either up or down, by use of inductor regulators of which there is one for each rotary. In a similar manner the potential for alternating current distribution is regulated by the setting of the multipoint switches at any point between 2,100 and 2,700 volts, depending on the load.

The use of six-phase transformers and converters is novel. The reason for the adoption of six-phases instead of three-phases was to secure the advantages of reduction of copper losses in the ar-

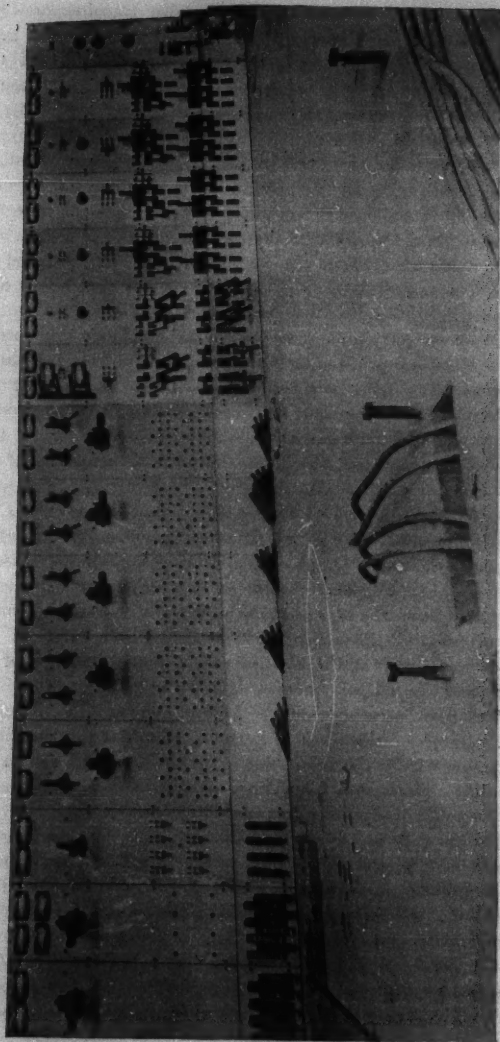


FIG. 12—Switchboard, Cedar Street Edison Station.

mature, and the accompanying reduction of temperature and its better distribution. At first sight it might seem that the increased complexity involved in the use of six-phases would not counter-balance the advantages to be gained. Practically, however, the use of six rings and the necessary additional taps to the windings on the armatures amounts to nothing in the operation of the machines. The dividing of the secondary windings on the transformers for two independent circuits results in no complication or expense. On account of the large current, the use of six conductors between the transformers and switchboard and between the switchboard and rotaries, was necessary whether three-phase or six-phase machines were installed. The switchboard is practically the same for either number of phases, except that the number of main switches was increased from two to three. This disadvantage, however, may be disregarded when a decided increase in the capacity of the rotaries is secured. The rotaries are ordinarily started from the direct-current end but are equipped with break-down field switches and designed for starting from the A. C. end where necessary.

Fig. 12 illustrates the alternating current switchboard, which is about 35 feet in length and eight feet in height.

On the extreme left is a relay panel through which current is usually distributed by means of four-conductor cables to one of the old steam generating plants. This plant will be used as a relay station and in case of a break-down in the water power transmission plant, current will be supplied from it to the sub-station. The second panel from the left is a transformer panel connecting either set of the static transformers supplying current for alternating current distribution to either of the two sets of four 'bus-bars. Each two-phase circuit is provided with two Stanley recording wattmeters (not shown), two ammeters, two recording wattmeters, a four-pole oil switch and fuses.

The panel next adjacent on the right controls the power distributing two-phase circuit. On this panel are also eight small double pole switches each of which controls the current to the magnets releasing the latches of three of the 25,000, volt switches. The five following panels each control two single phase alternating current lighting circuits. Each of these panels is provided with an ammeter, automatic oil circuit breaker and oil switch in series with plug switches. There will be noticed a number of holes in these panels which are designed for the plug switches, permitting the plugging of

any single-phase feeder onto any pair of the eight 'bus-bars. The double-pole plugs used are shown in the illustration lying in a pile at the foot of these panels.

Next come six alternating current rotary panels supplying current at 78 volts to the alternating current end of the rotary converters. These panels are provided with three two-pole switches for the six-phase circuit, also indicating wattmeter and main ammeter, thus giving an indication of the power factor of the load. There is also the handle of the field rheostat, a direct current starting switch, double-pole, double-throw field-switch, synchronizing plug and lamp and a small direct current two-pole, double-throw switch controlling the motor actuating the six-phase inductor regulators. The inductor regulators are placed on the floor directly behind the A. C. rotary panels.

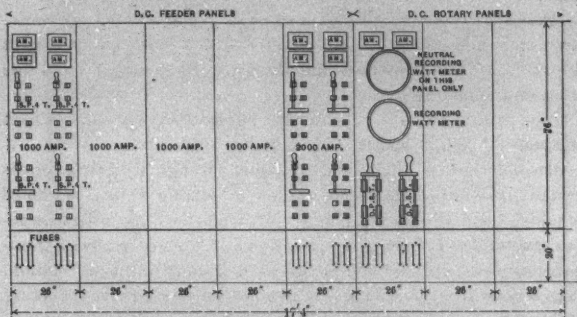


FIG. 13—Direct Current Switchboard.

The extreme right hand panel contains a double-throw direct current switch, a starting rheostat switch and an automatic circuit breaker, through which is supplied and controlled the direct current from the Edison system used in separately exciting and starting the rotary converters. On this panel there are also three multipoint voltmeter switches, through the use of one of which the voltage of any of the Edison feeders or rotary converter 'bus-bars at the other switchboard (See Fig. 13) may be shown on the direct current voltmeters hinged on the right of the board (not shown in the illustration Fig. 12.) The other two voltmeter switches in conjunction with the swinging alternating current voltmeters shown on the left of the A. C. rotary panels

permit the reading of the potential of any of the alternating current feeders or alternating current end of the rotary converters.

The direct current three-wire switchboard, about 18 feet long and eight feet high, (Fig. 13) is at right angles to the board just described. It consists of eight panels, three for the direct current end of the rotaries and the remainder for the feeders of the Edison three-wire distributing system.

Each direct current rotary panel controls the current from a pair of rotaries operating together on the three-wire system.

The Edison feeder panels are provided with single pole, four-way switches of special design which permit the throwing of any feeder on any one of four sets of 'bus-bars. Three of the 'bus-bars may be supplied at different potentials from each of the three pairs of rotaries. The fourth set of 'bus-bars is designed for use in connection with the storage battery, when same shall be installed. It will thus be seen that great flexibility in distributing potential is attainable, for, if necessary, the battery can be used independently of the rotaries, making a fourth and independent voltage available for feeder service. The illustrated diagram of the direct current switchboard shows the instruments and their arrangement sufficiently clearly to render their enumeration unnecessary.

The static transformers and rotary converters were furnished by the General Electric Company. The General Incandescent Arc Light Company furnished the high-tension switches and both switchboards, the latter being equipped with indicating instruments mainly manufactured by the Wagner Electric Manufacturing Company.

TESTS.

A report of the tests of the hydraulic and electrical apparatus might prove commonplace, but the following relating to the overhead transmission line and underground cables may be of interest because little data has been published with regard to the charging current of overhead lines and nothing whatever, as far as the writer is aware, regarding high-tension cables.

The first tests made were simply to ascertain whether the cables could carry the voltage under which they were to operate. The paper cable was first tested, the voltage being gradually raised to 30,400 volts. This was on the afternoon of October 14th, which I believe, marks the date of any attempt to carry

such high potential underground in connection with any commercial plant. The rubber cable was successfully tested about two weeks later in the same way.

In making measurements and in the following data on the charging current of overhead lines and cables, no allowance is made for any leakage current, as exhaustive and careful tests made on high-tension lines at Telluride by Mr. R. D. Mershon prove that with proper insulators, with no precipitation and with the voltages here used, any leakage current is inappreciable.

The charging current was measured by placing in the high potential circuit, a Stanley hot-wire ammeter reading from zero to thirteen amperes. The Stanley meter was compared with a Weston portable ammeter reading from zero to 15 amperes, which had just been calibrated at the Weston laboratory. The difference in readings between the two ammeters was small, but corrected readings are given in the accompanying curves. The voltage readings were taken by a newly calibrated Weston portable voltmeter connected to the secondary of a small transformer, having a ratio of one to two-hundred and designed and built especially for voltmeter measurements by the Pittsburg Transformer Company. The voltmeter used was compared during the tests with another portable Weston voltmeter with which it agreed closely. It was also compared with a General Electric switchboard voltmeter and the practical correctness of the instrument used was verified.

The alternations of the generators supplying current for the charging tests were kept constant by maintaining the speed constant as shown by a tachometer. No measurements were made as to the wave forms of the generators.

In making all charging current measurements, only two generators were used. For supplying the current at the generating station, where most of the tests were made, one of the 300-revolution General Electric generators there installed, was employed, which by reason of the source of its power, could easily be kept at a uniform speed. At St. Paul, a Westinghouse revolving armature 400-revolution 375 k. w. 60-cycle machine was used.

Fig. 14 gives the curves as plotted from the actual measurements of the charging current to one of the three-conductor overhead lines, also to two of the three conductors also to the three-conductor line connected to the paper cable, also two three-conductor overhead lines connected one to the paper cable and the other to the rubber cable, both circuits

being in multiple with one another, and supplied with three-phase current. The four above measurements were made from the generating station. There is also shown a curve for the paper cable as measured from the St. Paul end by the Westinghouse generator.

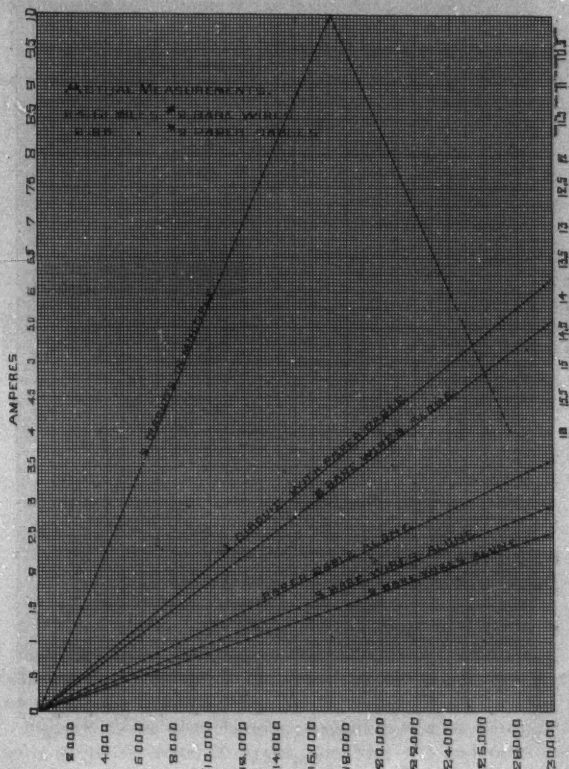


FIG. 14.

Measurements on both overhead lines showed that the charging current to either line was practically the same as that to the other. Furthermore, it was found that the charging current to

one line was practically the same whether both ends of the other line were left disconnected from everything, or whether its three conductors were tied together and connected to good ground.

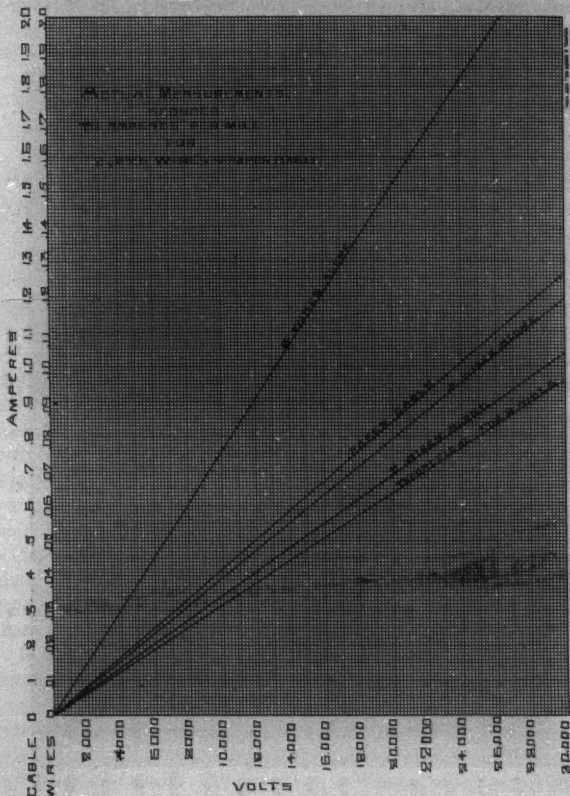


FIG. 15.

Fig. 15 shows the charging current as measured, reduced to amperes per mile for two, three and six wires (the latter being two three-phase circuits in multiple) and also for the paper cable. From some few measurements the charging current for the rub-

ber cable was found to be a little more than double that of the paper cable. This result from the standpoint of overcoming the reactance in the circuit, would make the use of a rubber cable the most desirable. It will be noticed that the charging current for two wires of the three-phase circuit is appreciably less than when voltage is applied to all three conductors. It checks very closely with what would be expected as figured. There is also shown a dotted line indicating the charging current as plotted from the formula for capacity between two wires. Lack of agreement between the theoretical and measured curves

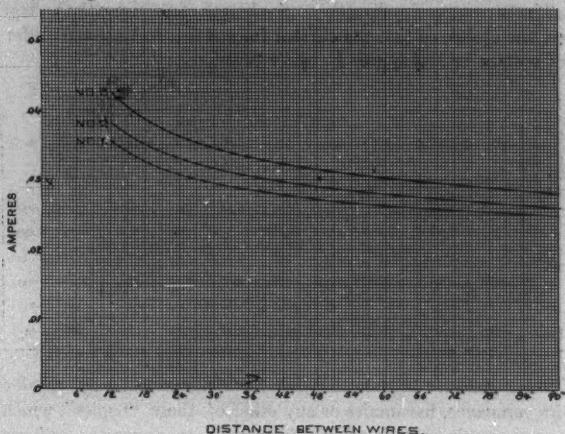


FIG. 16.—Variations in Charging Current due to Separation of Wires.

No. 1 No. 4 Wire.
No. 2 No. 1 "
No. 3 No. 0000 "
10,000 Volts.

is no doubt mainly due to the departure of the generator wave from that of a true sine curve.

Fig. 16 shows the charging current per mile per pair of wires at 10,000 volts, 60 cycles, for Nos. 4, 1 and 0000 conductors with the wires separated from 12 to 84 inches.

These curves were drawn in determining the advisable distance at which to space the conductors, and are here given as illustrating the comparatively small advantage to be gained in the way of reducing the charging current by separating the conductors,

after a distance of about three and a half or four feet between wires is reached.

The following data on charging current taken from the writer's note book may be convenient for reference, and is therefore here included because it has never before been published.

CALCULATED CHARGING CURRENT.

Two parallel wires : Length one mile : 10,000 volts :
Sine wave : Sixty cycles :

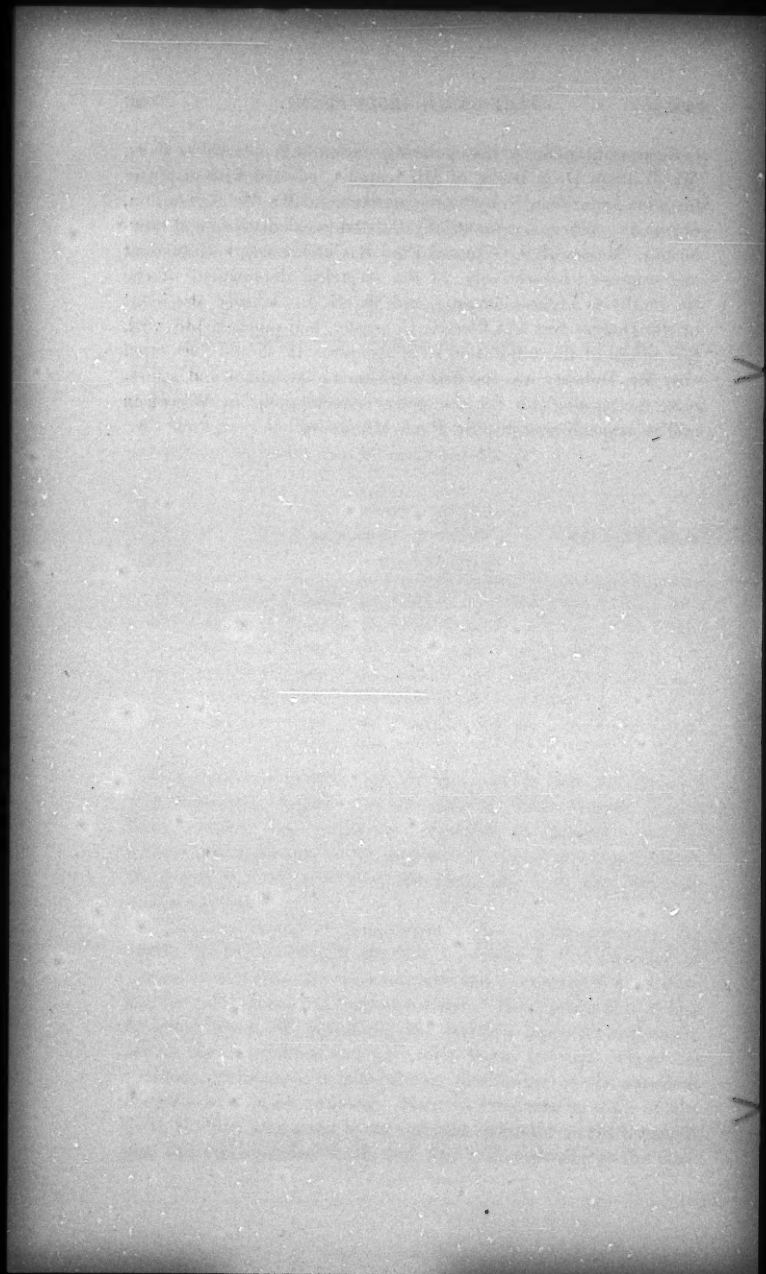
The current varies directly as the length of the line, the voltage and the cycles, so that the current for any given line and different voltage or cycles may be easily calculated :

Distance between centers of wires.	Size of Wire—B. & S. Gauge.									
	6	5	4	3	2	1	0	2/0	3/0	4/0
	Amperes at 60 cycles.									
18"	.0313	.0317	.0324	.0332	.0339	.0351	.0358	.0366	.0373	.0386
24"	.0405	.0402	.0408	.0415	.0422	.0433	.0437	.0444	.0454	.0462
30"	.0485	.0490	.0497	.0502	.0508	.0516	.0523	.0530	.0538	.0546
36"	.0526	.0528	.0537	.0543	.0549	.0555	.0562	.0569	.0576	.0583
42"	.0569	.0574	.058	.0585	.0591	.0596	.0603	.061	.0616	.0624
60"	.0735	.0760	.0764	.0769	.0774	.0780	.0785	.0791	.0798	.0803

It is a pleasure to state that we have never had any trouble with resonance, harmonics or any other of those "bogies" which have proved in some instances destructive to apparatus and are a cause of disquietude to the engineer of almost any long distance transmission plant, until after the same has been put into successful operation.

This paper would be incomplete without acknowledging the credit due to the writer's associate, Professor R. C. Carpenter, of Cornell University, for his assistance and co-operation in designing the mechanical and hydraulic plant. Much praise should also be given Mr. L. W. Rundlett, our resident inspector and engineer on the mechanical and hydraulic work, through whose experience, patience and faithfulness, the results of the excellent concrete work were attained. Mention must also be made of Mr. J. L. Harper, who acted as our resident inspector on the transmission line and electrical work, and who is now serving as the Gen-

eral Superintendent of the operating station at Apple River Falls. Mr. William De la Barre, of Minneapolis, advised with us from his wide experience in hydraulic matters, and Mr. W. A. Gordon, of our own office, has materially assisted in calculations and tabulations. Messrs. H. J. Gille and Fred R. Outcheon, superintendent and engineer, respectively, of the electrical department of the St. Paul Gas Light Company, and Mr. H. L. Doherty, president of the Denver Gas and Electric Company, had much to do with the design of the sub-station switchboards. It should be stated that Mr. Doherty was the first engineer to recognize and appreciate the possibilities for the power development in Wisconsin and its transmission into St. Paul, Minnesota.



ON THE MECHANICAL FORCES IN DYNAMOS CAUSED BY MAGNETIC ATTRACTION.

—
BY B. A. BEHREND.
—

Some years ago, when designing with Dr. Behn-Eschenburg alternating current machinery for the Oerlikon Engineering Works, Switzerland, we encountered formidable difficulties in diminishing the air-gaps in induction motors and in inductor generators. Everybody who has designed large generators or motors with small clearance, is aware of the tremendous mechanical effect of the magnetic forces, and of the necessity for abolishing their cause lest an otherwise successful design be balked by the bending of the shaft or even by the collapse of the magnetic frame. It was therefore of the greatest importance to us to calculate as exactly as possible the mechanical effects that were produced by unequal distribution of the lines of induction around the circumference of the armature, if the axes of armature and field were not coincident but eccentric.

In the text-books on dynamo-electric machinery this subject is generally very briefly treated and a formula is given which allows the calculation of the mechanical force of a piece of iron in a uniform magnetic field formed by two parallel surfaces, as represented in Fig. 1. This, however, is a hypothetical case of hardly any practical importance, if I except the device designed by the Oerlikon Works for counterpoising the heavy shafts and wheels of vertically arranged turbines. It is probably given for the sake of its simplicity and as the magnetic analogy to Lord Kelvin's absolute guard-ring electrometer.

From Maxwell's dynamical theory of the stresses in the magnetic field follows that the attraction between the armature A and the field F is equal to

$$(1) \dots \dots \dots Z = \frac{1}{8\pi} \mathcal{H} \mathfrak{B} S.$$

In this formula $\mathcal{H}$ is the magnetizing force, $\mathfrak{B}$ the induction, S the surface penetrated by the lines of induction. As all quantities are expressed in c. g. s. units, $\mathfrak{B}$ is measured in dynes.

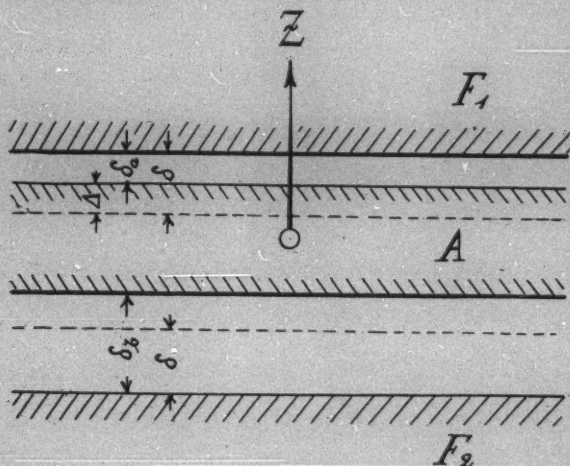


FIG. 1.

The formula (1) is generally, though incorrectly, written thus:

$$(1a) \dots \dots \dots Z = \frac{1}{8\pi} \mathfrak{B}^2 S.$$

As in air $\mathfrak{B}$ is numerically equal to $\mathcal{H}$, the formula (1a) gives the same numerical result as (1), but it should not be forgotten that $\mathfrak{B}$ and $\mathcal{H}$ are two quantities as different in kind as mass and force.

With the help of (1) we can write down at once the resulting attraction of the surfaces F_1 and F_2 upon the body A .

If A is in the middle between F_1 and F_2 , the distance between A and F_1 is equal to the distance between A and F_2 ; we will denote it by δ . The unsymmetrical position of A is determined by the clearances δ_a above A , and δ_b below A . Similarly we denote the induction in the air-gap above A by the index a , and below A by the index b . The induction that prevails if A is in the symmetrical position is denoted by $\mathfrak{B}$ without an index.

We now have

$$Z = \frac{S}{8\pi} (\mathfrak{B}_a^2 - \mathfrak{B}_b^2)$$

We obviously can express $\mathfrak{B}_a$ and $\mathfrak{B}_b$ by $\mathfrak{B}$, viz.:

$$\mathfrak{B}_a = \mathfrak{B} \frac{\delta}{\delta - d}$$

and

$$\mathfrak{B}_b = \mathfrak{B} \frac{\delta}{\delta + d}$$

hence,

$$Z = \frac{S}{8\pi} \mathfrak{B}^2 \left[\left(\frac{\delta}{\delta - d} \right)^2 - \left(\frac{\delta}{\delta + d} \right)^2 \right]$$

This can be written thus:

$$\begin{aligned} Z &= \frac{S}{8\pi} \mathfrak{B}^2 \left[\frac{1}{\left(1 - \frac{d}{\delta}\right)^2} - \frac{1}{\left(1 + \frac{d}{\delta}\right)^2} \right] \\ &= \frac{S}{8\pi} \mathfrak{B}^2 \left[1 + \frac{2d}{\delta} + \left(\frac{d}{\delta}\right)^2 - 1 + \frac{2d}{\delta} - \left(\frac{d}{\delta}\right)^2 \right] \end{aligned}$$

Neglecting $\left(\frac{d}{\delta}\right)^2$ in the denominator as a very small quantity, we arrive at the very simple expression of Z in dynes

$$(2) \dots\dots\dots Z = \frac{S \mathfrak{B}^2}{8\pi} \cdot \frac{4d}{\delta}$$

This expression of the attractive force is very perspicuous, and it permits of rapid and easy calculation, as δ and $\mathfrak{B}$ are known from the design. The only drawback, great enough, however, to make this formula inapplicable to dynamos, is that it supposes

that by a displacement Δ the air-gap is equally diminished at all parts of the circumference, which would be true in dynamos only if the diameters of armature and field were infinitely great, and very nearly in bipolars in which the arc subtended by the pole is small. As will presently be shown, this formula yields results for Z considerably greater than the real values, and this is what should be expected as in the case of dynamos a certain displacement of the rotor causes an equal diminution, or increase, of the air-gap only in the one point lying in a plane laid through the axes of rotor and stator, whereas in a plane perpendicular to this no diminution or

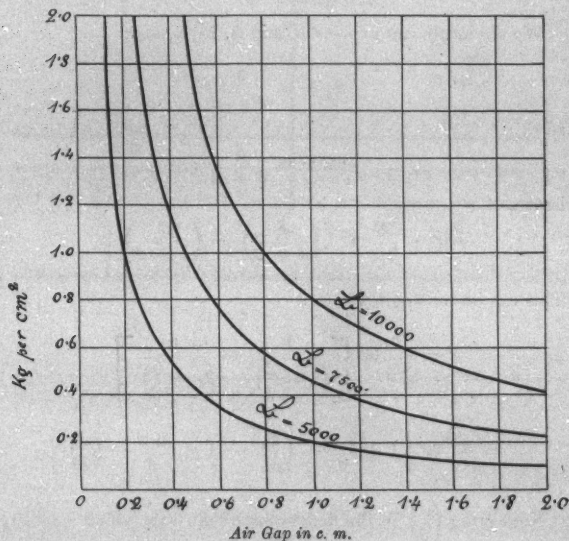


FIG. 2.—Curves illustrating the Magnetic Attraction Z as a Function of the Air Gap, and of the Induction with an Eccentricity $\Delta = 0.05$ c. m.

increase of the air-gap takes place. Hence the whole surface S is not active, but only part of it.

In a machine whose characteristic has been measured, $\mathcal{G}$ can easily be calculated, whereas it would be difficult to find $\mathcal{G}_a$ and $\mathcal{G}_b$. In fact, in order to find their numerical values, one would have to calculate $\mathcal{G}$ first, and then express $\mathcal{G}_a$ and $\mathcal{G}_b$ by means of δ , and δ_b .

Our formula (2) shows that for a given induction $\mathfrak{B}$ the magnetic attraction is directly proportional to the displacement Δ , inversely proportional to the air-gap δ . Assuming that a certain eccentricity of armature and field will be unavoidable, we see that Z increases rapidly with a diminution of δ .

To give a clear idea of this relation I give some curves in Fig. 2, the ordinates of which represent the magnetic pull in kg. per cm.², while the abscissæ represent the air-gap in cm. The displacement Δ is assumed to be equal to 0.05 cm. A glance at Fig. 2 is sufficient to make a designer wary when the diameters of his machines assume values of fifteen feet and more, the frames having to resist collapse like the flues of boilers.

But my object in presenting this paper is not to expound the corollaries of formula (2), well-known as they certainly are to every thoughtful electrician. I want to deduce a new formula strictly applicable to the case represented by dynamos, and show its agreement with observation.

For this purpose let us consider the case of two cylinders as represented by Fig. 3. We assume that there is all around the circumference the same magneto-motive force $\int \mathfrak{H} d\delta$, and that the lines of induction choose the shortest path between the two surfaces. Their density is then inversely proportional to the clearance.

With reference to Fig. 3, we have then:

$$\delta_a = \delta - \Delta \cdot \cos \alpha$$

Δ is defined by

$$\Delta = \frac{\delta_b - \delta_a}{2}$$

Hence

$$\frac{\mathfrak{B}}{\mathfrak{B}_a} = \frac{\delta_a}{\delta} = \frac{\delta - \Delta \cdot \cos \alpha}{\delta}$$

$$\mathfrak{B}_a = \mathfrak{B} \cdot \frac{1}{1 - \frac{\Delta}{\delta} \cdot \cos \alpha}$$

The magnetic attraction acting upon a surface element of the area $b R d\alpha$, in which b is the width of the laminations, directed towards the center, is

$$df_c = \frac{1}{8\pi} \mathfrak{G}_a^2 b R d\alpha$$

The horizontal components of this force on either side of the line of symmetry balance each other, the remaining vertical component being

$$df = \frac{1}{8\pi} \mathfrak{G}_a^2 b R d\alpha \cos \alpha$$

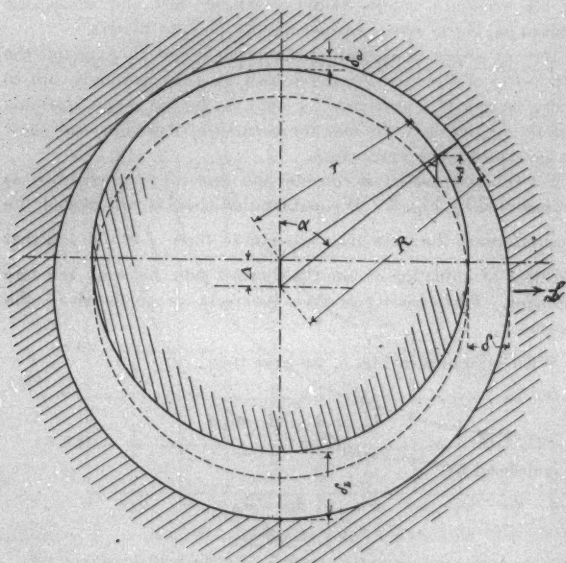


FIG. 3.

Substituting into this expression the value for $\mathfrak{G}_a$ found above, we have

$$df = \frac{1}{8\pi} b R \mathfrak{G}^2 \frac{\cos \alpha d\alpha}{(1 - \frac{D}{\delta} \cos \alpha)^2}$$

$$= \frac{1}{8\pi} b R \mathfrak{B}^3 \frac{\cos a \, da}{1 - \frac{2\Delta}{\delta} \cos a + \left(\frac{\Delta}{\delta} \cos a\right)^2}$$

Neglecting $\left[\frac{\Delta}{\delta} \cos a\right]^2$ as small in comparison with $\frac{2\Delta}{\delta} \cos a$,

we get

$$df = \frac{1}{8\pi} b R \mathfrak{B}^3 \frac{\cos a \, da}{1 - \frac{2\Delta}{\delta} \cos a}$$

$$= \frac{1}{8\pi} b R \mathfrak{B}^3 \frac{1 + \frac{2\Delta}{\delta} \cos a}{1 - \left[\frac{2\Delta}{\delta} \cos a\right]^2} \cos a \, da$$

$$= \frac{1}{8\pi} b R \mathfrak{B}^3 \left[1 + \frac{2\Delta}{\delta} \cos a\right] \cos a \, da$$

By integrating this expression between the limits 0 and $\frac{\pi}{2}$ we find the vertical component of the magnetic attraction in one quadrant. Hence

$$\begin{aligned} \int_0^{\pi/2} df &= \frac{1}{8\pi} b R \mathfrak{B}^3 \int_0^{\pi/2} \left(1 + \frac{2\Delta}{\delta} \cos a\right) \cos a \, da \\ &= \frac{1}{8\pi} b R \mathfrak{B}^3 \left[\int_0^{\pi/2} \cos a \, da + \frac{2\Delta}{\delta} \int_0^{\pi/2} \cos^2 a \, da \right] \\ &= \frac{1}{8\pi} b R \mathfrak{B}^3 \left[\left. \sin a + \frac{2\Delta}{\delta} \left. \frac{1}{2} \sin 2a + \frac{2\Delta}{\delta} \left. \frac{a}{2} \right|_0^{\pi/2} \right] \right] \end{aligned}$$

$$(3a) \quad f_a = \frac{1}{8\pi} b R \mathfrak{B}^3 \left[1 + \frac{2\Delta}{\delta} \frac{\pi}{4}\right]$$

Similarly we find for the vertical component of the attractive force directed downwards the expression

$$(3b) \quad f_b = \frac{1}{8\pi} b R \mathfrak{B}^2 \left[1 - \frac{2}{\delta} \frac{\Delta}{4} \right]$$

Hence

$$(3c) \quad f_a - f_b = \frac{1}{8\pi} b R \mathfrak{B}^2 \frac{4}{\delta} \frac{\Delta}{4}$$

This is the resultant of all the vertical components on one side of the line of symmetry. To find the total force we must multiply by two and we thus arrive at

$$(3) \quad Z = \frac{1}{8\pi} S \mathfrak{B}^2 \frac{2}{\delta} \Delta \text{ dynes,}^*$$

in which

$$(3d) \quad \begin{cases} S = \pi R b \\ \Delta = \frac{\delta_b - \delta_a}{2} \end{cases}$$

A comparison of formulas (2) and (3) shows at a glance that (2) yields an attractive force twice as large as (3).

Formula (3) is of great practical importance and interest as it is the correct expression for the magnetic attraction between two cylinders the axes of which are slightly displaced towards each other.

I will now give the result of some experiments on magnetic attraction which were made with a 300-H. P. inductor generator for 2,000 volts, a cross-section of which is represented in Fig. 4. The data of this machine were the following:

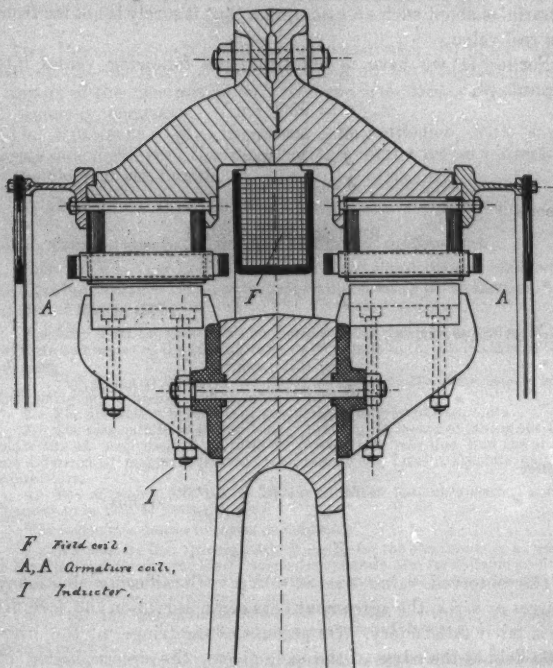
Number of R. P. M.	168
Frequency per second	50
Pole-horns on each side	18
Bore of field	260 cm.
Width of laminations	23 cm.
Number of coils on each armature	36
Number of turns of each coil	7
All coils in series.	
Air-gap above	0.26 cm.
Air-gap below	0.46 cm.

The bearings of the generator were opened and the field was excited while the inductor was standing still. At 18 amperes

*The derivation of this formula was looked over by Dr. Behn-Eschenburg. I feel, therefore, confident that it is not marred by any important mistake.

excitation the inductor I , with shaft weighing 8,400 kg., was lifted up from the bearings until it clung to the armature frame. The excitation was then lowered to eight amperes, when inductor and shaft dropped back into the bearings.

(1) At 18 amperes excitation and 50 P. P. S. the generator gave 1,400 volts on open circuit, whence follows $\mathcal{B} = 5900$.



F Field coil,
 A, A Armature coils,
 I Inductor.

Cross-section of inductor generator on which tests were made. Bore 260 cm.

FIG. 4.

(2) At eight amperes excitation and 50 P. P. S. the generator gave 640 volts on open circuit, whence $\mathcal{B} = 2700$. But it must be remembered that in our attraction experiment we should take into consideration that the magnetism at eight amperes excitation was attained by lowering the excitation, and as in inductor

generators the descending curve of magnetization lies often as much as 20% above the curve of ascending magnetization, this should be taken into account. In a paper published by the *Electrical World and Engineer*, I have enlarged upon this point and I may therefore here refer to it.¹ We therefore assume that $\mathcal{B}$ is 3100 instead of 2700; of course, there hangs the flavor of arbitrariness about such an assumption, but it surely is not far from the real value.

For test (1) we have to substitute the following values into formula (3):

$$S = 9350 \text{ cm.}^2$$

$$\mathcal{B} = 5900 \text{ c. g. s.}$$

$$d = 0.1 \text{ cm.}$$

$$\delta = 0.36 \text{ cm.}$$

Hence

$$Z = \frac{9350 \times 5900^2}{8\pi} \frac{2 \times 0.1}{0.36} \text{ dynes}$$

$$Z = 7400 \text{ kg.}$$

For test (2) we have:

$$S = 9350 \text{ cm.}^2$$

$$\mathcal{B} = 3100 \text{ c. g. s.}$$

$$d = 0.36 \text{ cm.}$$

$$\delta = 0.36 \text{ cm.}$$

Hence

$$Z = \frac{9350 \times 3100^2}{8\pi} \frac{2 \times 0.36}{0.36} \text{ dynes}$$

$$Z = 7340 \text{ kg.}$$

The observed value was 8400 kg. Considering the many sources of error, the agreement between observation and formula (3) is fairly satisfactory. On account of the fringes of the magnetic field at the edges of the pole-pieces, the determination of the exact value of S is left to the judgment of the designer. As the attractive force is also directly proportional to the square of the total flux, and inversely proportional to the surface S , it follows that if we had estimated S 5% too large, Z according to formula (3) must be 5% too small.

I hope that formula (3) will make some friends among designing engineers.

1. *Electrical World and Engineer*, Jan. 20, 1900.

THURSDAY, MAY 17TH, 1900.

MORNING SESSION.

THE PRESIDENT:—We will now proceed with the other business of the meeting. The first thing on the program is the "Report of the Committee on Units and Standards," by Dr. A. E. Kennelly, chairman.

DR. KENNELLY:—Mr. President and gentlemen, with your permission I will read the report of the committee as addressed to the Council last month.

REPORT OF COMMITTEE ON UNITS AND STANDARDS.

TO THE COUNCIL, AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

GENTLEMEN:—Your Committee on Units and Standards has considered the following resolution passed at the last regular meeting of the INSTITUTE on the 28th of March, 1900:

Resolved: That the Committee on Units and Standards be requested to investigate and report at the ensuing meeting in regard to the advisability of the following:

1. The giving of names to the Absolute Units of the Electrostatic and Electromagnetic systems.
2. The denotation by means of prefixes of multiples of such units.
3. The rationalization of the present system, by means of taking the absolute unit of magnetism as equal to the present magnetic line, and the absolute difference of magnetic potential as equal to the present absolute unit of current-turn.
4. The advisability of taking up any or all of the above matters at the Congress to be held in Paris this year.

The Committee desires to report as follows:

1. We consider that there is need for names for the absolute c. g. s. units in the Electrostatic and the Electromagnetic systems; also for suitable prefixes to denote decimal multiples and submultiples of these units, in supplement and addition to those already in common use.

2. That the International Electrical Congress convening this year at Paris should be urged to bestow the above mentioned names and create said decimal prefixes.

3. That much advantage would accrue to a universal "rationalization" of electric and magnetic units, and that the Congress be requested to consider the means and advisability of such "rationalization."

4. That we recommend that the whole subject should be brought up as a topic for general discussion at the approaching General Meeting of the INSTITUTE in Philadelphia.

Signed

F. B. CROCKER,
W. E. GEYER,
G. A. HAMILTON,
A. E. KENNELLY, Chairman,
W. D. WEAVER.

DR. KENNELLY:—Mr. President, I would ask permission to add a few remarks on these resolutions. I do not know that I am speaking for the committee, although I have no reason to suppose that my remarks are contrary to their views.

We have a very beautiful system of units, which, as we all know, are those of the centimetre-gram-second system. We are taught the great advantage which accrues to the profession from the use of those units, and their great value from a scientific standpoint; and then after we have learned to estimate the beauty and recognize the importance of these units we are told that we must throw them away, for all practical purposes of electrical work, and come down to another system, related thereto in a rather complex fashion, to wit, the volt-ampere-ohm system. The volt-ampere-ohm system, is such a system as would be developed if instead of a centimetre of length we employed a thousand million, or a billion of such centimetres, which is practically the distance from the pole to the equator, along the meridian of the earth passing through Paris. The unit of time in that system is the second, the same as in the c. g. s. system; but the unit of mass instead of being the gram is 10^{-11} gram. I don't know how to name that quantity. The unfortunate part of this practical system is that, as we extend it, in order to make both ends meet in our equations, and in order to make it consistent, we have to employ a unit of length equal to the earth quadrant, which is a very unfortunate arrangement, because we do not build dynamos on that scale. The difficulty which confronts us is the anomalous condition of a theoretical system of units which is good but not practically used, and a practical system which is not so good but which is used, while the connection between the two systems is very perplexing and difficult to remember. There was no necessity, as we see it now, to create this present system. We do not need it, excepting so far as custom and practice has made it necessary. There was never any occasion for creating the volt; it would have been quite sufficient if the volt had been the c. g. s. unit itself, one hundred million times smaller and if the prefix had been attached to the word volt which would have signified a multiplication of a hundred million, exactly in the same way as the microfarad signifies a division of a million. That example shows how clearly we could have had a prefix, and all our terminology, all our equations and all our language would have been consistent with the fundamental c. g. s. system on that basis. There are many people who believe that it is unadvisable to create names for the c. g. s. units; they say it would complicate matters too much. Exactly the same reasoning, however seems to apply to animals and flowers, for example. There are hundreds of thousands of genera and species of animals and plants, either existing or that have existed in the past, and all of these that are known with any accuracy are scheduled and have names. Some of them are atrocious

names; but it is surely better to call a buttercup a *ranunculus bulbosus* than to call it by some number in a botanical catalogue or system. If we want to talk about units in the fundamental system we have to say so many units c. g. s. Now there is an unfortunate misunderstanding which is likely to attach to any such arrangement, because we have two c. g. s. systems, the electro-static and the electro-magnetic, and unless you say so many units electrostatic c. g. s., or else so many units electromagnetic c. g. s., you immediately invest your statement with some uncertainty; and therefore some name for each fundamental c. g. s. unit is desirable. We have a few names already, such as the dyne and the erg, and these names are of great utility and no one objects to them. We have metre, centimetre and gram, and those names do not give us any great disadvantage or trouble. Surely it would be no disadvantage to have additional names, even if we never used them; if they were laid on the shelf, the worst that would happen would be that they might be laid permanently on the shelf. The next point, about prefixes for multiples, is surely very important and self evident. We have at present the deka, hekto, kilo, myria and mega, only five prefixes to determine decimal multiples in the ascending scale. It reminds one very much of those savages in Africa who can only count one, two, three, four, five; and we smile at the simplicity of a language which is so imperfect that they are not able to express numerals further than that. Our own civilized nomenclature in electromagnetics is similarly defective considering that in our fundamental physical, electrical and magnetic system we have no multiple of units beyond five in the ascending scale and four in the descending scale. Prefixes for the multiples could be created whether we used them or not. They should be created and they should be consistent. If they are created properly, even at this time, thirty years after the original introduction of the system, we can so take up the practical system with the fundamental c. g. s. system as to give no inconvenience. We could then use the c. g. s. system in practical work, in spite of the fact that the other system is in universal use. The worst that could happen would be that the names would sink into innocuous desuetude. No harm would be done and much advantage might arise.

In regard to the question of the rationalization of units, we now know that the B. A. system might have been better constructed if the fundamental entities had been fluxes instead of point poles and point charges. In order to rationalize the units upon the proper scientific basis, and rectify the existing system, it would be necessary to change all our ohms, volts, amperes,—every electric unit that the electrician employs to-day. It would avoid endless trouble in contracts and endless trouble in machinery and labor. It is a most serious question. It is a question of the rationalization of units after they have been established, adopted by the governments, and after they have

been brought to universal use in the last thirty years. A suggestion, has, however, been made as a sort of half means of eradicating this trouble, a suggestion due to Professor Fessenden, I believe, and also to others; that is by employing the permeability of air circuits, the unit of which shall be four π instead of one; in other words giving to air a permeability equal to four π that we would be able to cancel out the four π in our equations; the μ would then be cancelled out the four π . That is a possibility that has been favorably discussed, although there are some who think it would be a disadvantage. The question is entirely separate from the question of giving names to the c. g. s. units. The two things must be considered each upon its own basis, and one proposition does not in any way interfere with the other. The committee has therefore agreed that this question of rationalization could be considered with advantage as to whether it is advisable. But we do not think there is any question as to the advisability of giving names to things which already exist.

THE PRESIDENT:—Gentlemen, this report is now before you for discussion. In view of the Congress in Paris this year this subject ought to be very fully ventilated and discussed at this meeting. The report, as you have seen, is very conservative and does not suggest any very radical changes. The question of naming the c. g. s. units is, as was very well shown by Dr. Kennelly, something which at least will do no harm and it may do much good; it therefore seems that there could hardly be any real objection raised against it. In order, however, to properly bring it before the Congress, it seems to me we ought to go prepared to suggest certain names and prefixes. At the Congress of 1891, in Frankfort, Germany, to which this INSTITUTE sent a delegation, of which I was a member, we tried to have certain things adopted, among other things the henry and the gauss, but we saw very soon that it was hopeless to try to introduce anything new at such a Congress. A Congress is an occasion to settle upon something which has been discussed thoroughly before the Congress meets; it is hardly the place to bring out something new, to discuss it, and then to decide on it. It would therefore be very desirable if we could formulate our recommendations to the Congress and have them published at once, so as to give the Europeans a chance to look them over and consider them. If we wait until the Congress meets and then bring up these matters, it will no doubt result in failure to adopt our suggestions.

There have always been objections to introducing any new system of units; but nevertheless it seems to me that it would be well to have an entirely new system, perhaps something like the one proposed by Heaviside, which would be of great benefit to scientists and to physicists, even though it might be quite different from the one used in practice. In my opinion there would be no objection to adopting a perfectly rational system of physical

units in order to enable physicists and scientists to work with it; when they wish to connect their results with those stated in practical units they can do so very readily. If such a system of physical units turns out to be much better than the present c. g. s. system, it will find its way into practice in the course of time; perhaps not during our lives, but later; its foundation would be laid. Therefore I think that the more rational and the more thorough such a new system of physical units is, the better. If we are going to adopt anything new let it be something which will require no further changes later on.

As to the system of practical units, it seems to me that it is not necessary to have any specific practical units at all. In other systems of measurement that we deal with, such as those of weight, length, and so on, we have no practical units. We use the meter when that is the most convenient; we sometimes use the centimetre or the inch or the mil or the mile. It is not necessary to decide that any one of these lengths should be called the unit; we use whatever unit happens to be the most convenient. If we had a system of c. g. s. units with names, there is no need of saying that just so many c. g. s. units shall be determined upon as a practical unit, and be called by another name.

The report is open for discussion.

MR. C. O. MAILLOUX:—I wish to call attention to one instance in which a unit has been named and has afterward fallen into innocuous desuetude, to use the language of Dr. Kennelly. Before the Congress of 1881, at which time the ampere, the practical unit of current, had not yet been named, there was a tendency, especially among the Germans, to use the word *weber* for that purpose; and at the Paris Congress of 1881 there was a certain amount of contention between the advocates of the word *weber*, and those of the word *ampere*, as the practical unit of current flux. The strife was quite sharp and I believe it was finally settled by giving the name *ampere* to the practical current unit, and giving the name *weber* to the c. g. s. unit; so that to-day we have, at least theoretically, the name *weber* to express a unit equal to ten amperes. In other words, to put it differently, our ampere is really a *deciweber*, as it stands to-day. It seems that this application of the word *weber* became forgotten, from sheer want of use, and it lay on the shelf. We never found use for a unit term of ten amperes and consequently we never had occasion to use the word *weber*. Later on, I think this INSTITUTE proposed to use the same word as a unit of magnetic flux; and if this suggestion should be adopted we would really find ourselves with the same name for two different units, one the absolute current flux value, and the other absolute magnetic flux value. This shows the importance of having a system in the formation of names. If at the time when the *weber* was christened, names had also been given to the other c. g. s. units, it is not likely that this word would have been forgotten; but it was

the only c. g. s. unit that received a name, and for that reason it became forgotten.

I myself think that the naming of the c. g. s. units is desirable, and I think that when we have these names, with a system of prefixes expressing multiples and submultiples, or else powers of ten, we will have all that is necessary for practical purposes. In different industries we use the centimetre as the unit. In watch-making, for instance, the centimetre is the fundamental unit. What corresponds to the foot of the carpenter is the centimetre of the watch-maker. The chemist uses the centimetre as the unit of length and uses the milligram as the unit of weight. In practical work we use the kilogram as a unit of weight. They are all based on the same thing, and the prefix milli, or kilo, added to the word gram, really makes the practical name and there is no need of a specific name in these cases. It seems to me that after all, the logical system is one that is self-explanatory. There is no objection to microfarad, because we know what it means; and it seems to me that when we have named the other units all we shall need will be a rational system of prefixes designating the multiples or subdivisions in the ascending and descending scales, respectively.

PROF. GOLDSBOROUGH:—I have been very much interested in these matters, the naming of the electromagnetic units and the rationalization of the system. I am heartily in favor of appropriate names being given to the electro-magnetic units, but at the same time some care should be used in extending them and in arranging for prefixes and suffixes. At the present time we use the words milliamperere, millivolt and kilogauss, and various other prefixes which indicate submultiples or multiples of units which we call our practical units, and they have to us a real value and they carry with them a real significance which it would probably take much time to efface and in their stead use prefixes or suffixes in conjunction with the c. g. s. units. Of course, as far as the word gauss is concerned, it has never been adopted by any International Congress. It is a word, however, which the INSTITUTE has sanctioned, I believe, in the same way that it has sanctioned the terms gilbert and weber. I do not know how generally they are used among engineers; but certainly to those who make use of them they become very valuable, and to my mind if any international names are given they should be in line with the suggestions of the INSTITUTE, if possible.

As regards the rationalization of the system of c. g. s. units, there seems to me to be very little in the way of carrying out the suggestions that have been brought forward and discussed, largely emanating from Prof. Fessenden. To my mind the electricians of the world will have no great difficulty in changing their mental attitude so as to prevent ambiguity of thought. In connection with the work of education, I think the future generations will owe us a debt of gratitude for making this change,

as it will make their concepts of the system of units with which we have to deal more clear. There may be some slight advantage in having the permeability of air unit but it is not a very pertinent one. I think when the idea is first presented to the student and he is told that the permeability of air is 4π , that will settle the matter for him, and there will be no further question or ambiguity in regard to it. The older students will have some difficulty in readjusting their mental concepts as regards the permeability of air. This, however, is a small matter in comparison with the great good that will result from these changes.

I think the committee acted very wisely in giving to us a conservative phraseology in their report. If we go before the International Congress with suggestions which affect all engineers, of all countries, we will have necessarily to be very careful about the recommendation of terms. It might be a good plan for our delegation to have in mind recommendations for naming these units, which the American engineers can back and heartily support. I presume in whatever names are given there will have to be a distribution of them among the various elements that are represented along the lines of nationality. However that may be, the work of the committee deserves our high commendation, and I hope a motion will be carried at this meeting which will give official sanction to the report which the committee has presented to us to-day.

PROF. W. S. FRANKLIN:—I have been very much interested in this matter of the improvement of our systems of electric units which has been discussed so much for the last two or three months, and I am in full accord with the report of the committee. There is just one thing that I would like to say in regard to the rationalization of units, and that is this: To most minds the eruption of 4π seems to be the only irrational thing in connection with our electrical units; but it seems to me that the most irrational thing is the fact that we have two systems. The fact is, I think, we are not ready to rationalize our units; I think it is an impossibility, because we do not know enough about the subject; so I think the committee has taken a very wise stand in not recommending the INSTITUTE to take a definite stand on that subject. On the other hand, I think it would be an immense advantage to adopt a simple series of names and prefixes for c. g. s. units and multiple units. For my part, I think that a teacher is more able to judge of the difficulties which are involved in our systems of units than practical men, because he has occasion every year, to go through, in a sort of way, the same experience that an engineer has to go through only once in his lifetime; that is, he observes others go through the formative period when they are becoming familiar with the theory of electricity. I think the greatest difficulty that I encounter in teaching the subject of electricity is due to the fact that the c. g. s. units have no names. The practical units

are the *practical units* because they have names. I heartily endorse the committee's action and I think the INSTITUTE ought to take steps to formulate its views on the subject for presentation to the Paris Congress.

MR. C. P. STEINMETZ:—I fully appreciate the fact that the absolute c. g. s. units, with the proper system of prefixes, would cover all the needs of electrical engineers and would be far preferable to the present system of c. g. s. units. But I do not think it proper at this late day to change over. The practical units, although inferior to the absolute system of units, have been introduced to such an extent that there is little probability they will ever be replaced. The name "weber" and one or two other names are rarely met. In replacing the present names of E. M. F., etc., I think we would find very great difficulty.

Coming to the system of prefixes, this is undoubtedly a very desirable proposition, as seen by experience, which has already introduced such prefixes as milli, mega, etc., but I should be strongly opposed to any attempt to introduce too many prefixes. When the metric system was introduced on the Continent, an attempt was made to introduce prefixes for every one-tenth in the ascending and descending scale. Practically all these prefixes have been discontinued, with the exception of kilo and milli, except in very few instances.

It appears to me that prefixes in the ascending and descending scale, following each other by thousands, would be sufficient, as milli and micro in the descending, and kilo and mega in the ascending scale.

With regard to the rationalization of our units, I do not agree with our committee. I think any attempt to rationalize our system of units would cause such a confusion as to be very undesirable, and I do not think that matters would be bettered thereby, since even such a rational system of c. g. s. units is not rational at all, as can easily be seen if you try to derive some unit from centimetre, gramme and second, in several different ways. If the system is rational you should get the same dimension no matter how you derive the unit. But in reality, starting from the action of magnetic masses upon each other, you get entirely different dimensions, as starting from the action of electric quantities upon each other. The reason is that neither of the two systems, the electromagnetic or the electrostatic, are rational, but in the former the assumption is made that the permeability of space is unity, in the latter the assumption that the dielectric constant of space is unity, and neither is obviously warranted. But there is another system of units, that is the mechanical system, where you would start by the gravitational attraction of unit masses upon each other in unit distance. Now it may be possible to bring the different systems into agreement by assuming for the dielectric constant of space and the permeability of space such values as to make the action of magnetic and electric

quantities upon each other to agree with the action of masses upon each other by gravitation, but such a change would be so far reaching that I do not think it could be introduced at this late day.

MR. MAILLOUX:—I wish to call attention to a suggestion which might be of interest in connection with the matter of prefixes. I know an eminent analytical chemist who uses frequently the terms centi and milli, repeating them to designate a submultiple. For instance, in analytical chemistry the word milligram is used to indicate the unit of mass, but my friend uses the terms decimilligram, centimilligram and millimilligram, and thus brings the value down to as low as the ten minus sixth power. So this represents a step in the right direction so far as the descending scale goes. It is possible that a similar expedient might be adopted for repeating the prefix terms in the ascending powers, and likewise bringing us up to the eighth or tenth exponent.

I think Mr. Steinmetz is in error when he says the term deci is not used. It is used very largely by French writers and also by German writers. The expressions decilitre and decimetre are both used largely, in both these countries and, of course decimetre and millimetre are used very extensively all over the world.

PROF. A. J. ROWLAND:—There are one or two trifling things that have occurred to me. I don't know that they will contribute very much value to the discussion. It seems to me the whole question of the desirability of more units hinges very much on whether you look at this thing from the standpoint of pure science, or the standpoint of engineering. I can see a great deal of use in giving special names to the c. g. s. units if these units are to be used by people who are interested in pure science, but I am not so sure that they would have so much value to engineers. We have two systems now which engineers have to know and handle, the foot-pound-minute system and the centimetre-gram-second system.

The advantages of the c. g. s. system are obvious to anyone who has used it at all, and yet in spite of its universal use by scientists the world over, and in spite of the legislation which has officially adopted it in this country, engineers scarcely use it at all in their work. Hence before engineers will use more c. g. s. units, they must come to use those we have already.

Some people have called attention to a possible confusion in the names given to c. g. s. fundamental units and c. g. s. practical units. There are difficulties in the use of units now at hand which are quite as bad. Take the magnetic units, for instance; take a unit which expresses the intensity of magnetic flux. One can speak of the intensity per square centimetre or square inch. When intensity of magnetic flux is mentioned I often find great uncertainty as to what is meant. When somebody comes to talk to me about intensity of magnetic flux and uses a number which is near to 100,000, I of course recognize that that is another

way of thinking about it than mine; that it is the intensity per square inch; but somehow my mind fails to get that particular grasp on the numerical quantity which attaches when the thing is in square centimetres.

Recently there has been a great deal of concession in the matter of units to the practical electricians. I don't know that it is particularly to be welcomed but the fact remains. Here is the matter of electromotive force, or difference of potential. Those terms are very rarely used among practical electricians, but quite often we hear the term "voltage"; and (much worse) how often do we hear the term "pressure." I don't know what a student of pure science or even an engineer can think of that. It seems to me that it is a great pity that in such matters there has to be a concession made. But in the matter of units, if we multiply units, it seems to me the practical electrician is the man who is going to hold to the old units to the very last possible extreme, and since concessions have already been made to him, concessions will doubtless have to be made in the future. The result will be that if there are units in the c. g. s. system and the pure scientist uses them, the engineer, in contact with practical electricians on one side and pure scientists on the other side is going to have a very hard time of it.

MR. STEINMETZ:—To illustrate what the last speaker said, I may give some of my experience. About eight years ago in the company with which I am connected, we used c. g. s. units for magnetic flux, etc., that is the metric system for the calculation of machines. At the present time we use lines of magnetic force per square inch, etc., because experience has shown that while for scientific reasons the c. g. s. units are the only correct ones, they are very inconvenient in practical design since all the dimensions ultimately have to be given in inches and a calculation in centimetres thus means constant transfer from one system to the other system, and the time is too short to do any work which is not necessary. It appears to me, therefore, that as long as the metric system is not used throughout the country, in machine shop practice, etc., the use of the metric system in design and calculation for practical application will remain limited.

THE PRESIDENT:—If there is no more discussion a motion will be in order concerning the disposition of this report.

PROF. GOLDSBOROUGH:—I move, Mr. President, that the report of the Committee be accepted and adopted by the INSTITUTE, and transmitted to the delegates, for presentation before the International Congress. Seconded and carried.

THE CHAIRMAN (PROF. OWENS):—The next thing on the program is a paper by Mr. Fitzhugh Townsend of Columbia University, on "The Relation Between Hysteresis and Eddy Current-Transformers." The paper will bring out a rather peculiar matter which he has noticed and will no doubt be of considerable interest.

Associate Members Elected at a meeting of the Executive Committee, held Thursday, July 12th, 1900-

ADLER, ALPHONSE A.	Electrician, New York Post Graduate Hospital, 20th Street and 2d ave., residence, 237 Eldridge St., N. Y.	F. E. Kinsman. W. A. Anthony. Ralph W. Pope.
AMBLER, WILLIAM.	Student at Cornell University, residence, 76 Lincoln Ave., Cleveland, Ohio.	Harris J. Ryan. Fred'k. Bedell. Edw. L. Nichols.
BARTON, PHILIP PRICE.	Assistant Superintendent, The Niagara Falls Power Co., Niagara Falls, N. Y.	L. B. Stillwell. Chas. F. Scott. A. J. Wurts.
BLISS, LOUIS DENTON.	Principal Bliss Electrical School, 614 12th Street, Washington, D. C.	G. K. Woodworth. C. W. Swoope. H. P. Hill.
FLEMING, JOHN F.	Electrical Contractor, Brookline, Mass.	Chas. B. Cross. Chas. H. Herrick. Chas. B. Burleigh.
GARTLEY, ALONZO.	General Manager, Hawaiian Electric Co., Honolulu, H. I.	C. L. Cory. A. M. Hunt. W. F. C. Hasson.
TINGLEY, E. M.	Westinghouse Elec. & Mfg. Co., residence, Amber Club, Pittsburg, Pa.	Chas. F. Scott. A. J. Wurts. L. B. Stillwell.
WESTON, SYDNEY F.	Assistant Engineer, Waldorf-Astoria Hotel, residence, 23 Gramercy Park, N. Y. City.	H. A. Storrs. Geo. F. Stever. Tom H. Gregg.
WOODSWORTH, PHILIP BELL.	Professor in charge of Electrical Engineering, Lewis Institute, Chicago, residence, 123 South Park Ave., Austin, Ill.	Albert Scheible. Geo. P. Nichols. E. A. Schweitzer.
ZANI, ARNALDO P.	Electrical Engineer, Thomson-Houston Co., Piazza Cartello 5 Milano, Italy.	C. P. Steinmetz. J. W. Lieb Jr. Philip Torchio.
Total 10.		

Associate Members Elected and Transferred at a meeting of the Executive Committee, New York, Thursday, July 26th, 1900.

ACKLAND, E. W.	Electrical Engineer, Perth Electric Tramways, Perth, Western Australia.	S. W. Childs. J. S. Fitzmaurice. W. G. T. Goodman.
ALLEN, ALBERT P.	General Inspector, American Tel. & Tel. Co., 15 Dey St., residence, 44 Irving Place, New York City.	John J. Carty. F. A. Pickernell. A. N. Mansfield.
AUEL, CARL B.	Engineer, British Westinghouse Elec. & Mfg. Co., Amber Club, East End, Pittsburg, Pa.	Chas. F. Scott. P. A. Lange. C. E. Skinner.

BAKER, ARTHUR O.	Superintendent, Wichita Gas, Electric Light and Power Co., Box 574 Wichita, Kansas.	F. E. Kinsman. Ralph W. Pope. H. D. McVay.
BERG, GEO. H.	New England Sales Agent, Bullock Electric Mfg. Co., 70 Kilby St., Boston, Mass., residence, Medford, Mass.	Robert T. Lozier. John L. Hall. C. V. Edwards.
CAENAGHAN, E. D.	In charge of machinery with Cipriano Guerrero, Durango, Do. Mexico.	C. F. Beames. R. H. Evans. M. T. Thompson.
DYSTERUD, EMIL	Superintendent and General Manager, Electric Light & Power Co., Monterey, Nuevo Leon, Mexico.	P. H. Evans. C. F. Beames. S. A. Dyer.
ELGIN, JAMES MEIKLE	Chief of Electric Dept. Edison Electric Light Co., of Philadelphia, 10th and Samson Sts., residence, 4230 Chester Ave., Philadelphia, Pa.	C. Toerring. Minford Levis. Wm. C. L. Eglin.
FARRAND, DUDLEY	General Manager, United Electric Company of New Jersey, 207 Market St., residence, 141 Clinton Ave., Newark, N. J.	Wm. Stanley. John F. Kelly. C. C. Chesney.
HARTER, BRET	Superintendent D. R. R. & L. O. Railway, Rochester, Mich.	C. G. Young. W. C. Burton. Harvey E. Molé.
HITZEROTH, L. D.	Superintendent, Electrical Department General Electric Co., 229 Stevenson St., residence, 452 Bryant St., San Francisco, Cal.	F. V. T. Lee. C. O. Poole. F. F. Barbour.
HOWLAND, LEWIS A.	Electrical Engineer Royal Electric Co., Montreal, Que.	P. G. Gossler. Robert A. Ross. R. B. Owens.
IMLAY, L. E.	Construction Engineer, Westinghouse Elec. & Mfg. Co., Niagara Falls, N. Y.	P. M. Lincoln. Chas. F. Scott. W. K. Dunlap.
KENT, JAMES MARTIN	Instructor in Steam and Electricity, Manual Training High School, Kansas City, Mo.	Jas. Lyman. L. Stieringer. E. R. Weeks.
KENNEDY, JEREMIAH J.	Mechanical Engineer with J. G. White & Co., 29 Broadway, New York.	H. A. Lardner. Wm. C. Burton. Geo. W. Frank, Jr.
McLIMONT, A. W.	With State Electrical Engineer, Gobirino de Guanajuato, Box 25, Guanajuato, Mexico.	C. F. Beames. P. H. Evans. S. A. Dyer.
NICHOLSON, SAMUEL L.	With Westinghouse Elec. & Mfg. Co., 120 Broadway, New York residence, 820 President St., Brooklyn, N. Y.	R. D. Mershon. Wm. K. Archbold. C. O. Mailloux.
PARKE, RODERICK J.	Consulting Electrical Engineer, 409 Temple Building, Toronto, Canada.	S. S. Wheeler. Chas. F. Scott. Norman Ross.

SMITH, WM. STUART	Consulting Engineer, Electrical and Mechanical. 2533 Dwight Way, Berkeley, Cal.	F. A. C. Perrine. J. A. Lighthipe. W. D. Weaver.
SMITH, WALTER F.	General Manager, United Gas Improvement Co., Philadelphia, Pa., residence, 2010 Ontario St., Philadelphia, Pa.	Herbert Lloyd. Chas. Blizard. R. H. Klauder.
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